Autonomous Spilled Oil and Gas Tracking Buoy System and Application to Marine Disaster Prevention System

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PARI

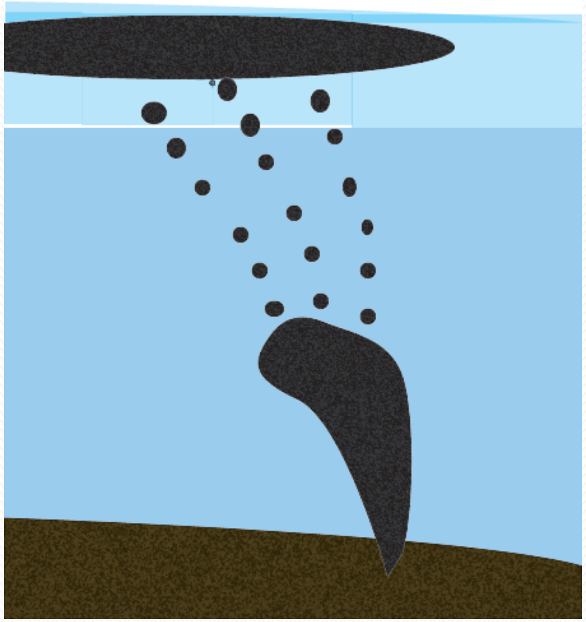
Background

Heavy disasters of oil spill on the sea have occurred in recent years such as "NAKHODKA Oil Spill" in Japan 1997, "Erica Oil Spill" in France 1999, "Prestige Oil Spill" 2002, and "Deepwater Horizon" in Gulf of Mexico 2010. Such oil spill accidents occasionally have occurred all over the world.

Spilled oil is emulsified by the intake of seawater and it results in high viscosity. Once it drifts ashore, its residual possibility along the beach becomes high.

Once oil and gas blow out from seabed by an accident of subsea oil production system or by a seismic activity in the area of ample reserves of methane hydrate in the sea, it seriously damages not only ships and airplanes, but also natural environment.

Oil and Gas Blowout from Seabed



- When, where and how much do the spilled oil and gas float up on the sea surface ?
- Where does the floating oil on the sea surface drift ashore ?

⇒ we need information of advection, diffusion and dispersion of underwater oil and gas, and its prediction.

Drifting Oil on Sea Surface

- Collect spilled oil on the sea before it drifts ashore

⇒ Current location data of spilled oil in real time

- Deploy the machineries for spilled oil adequately along the beach where spilled oil will drift ashore

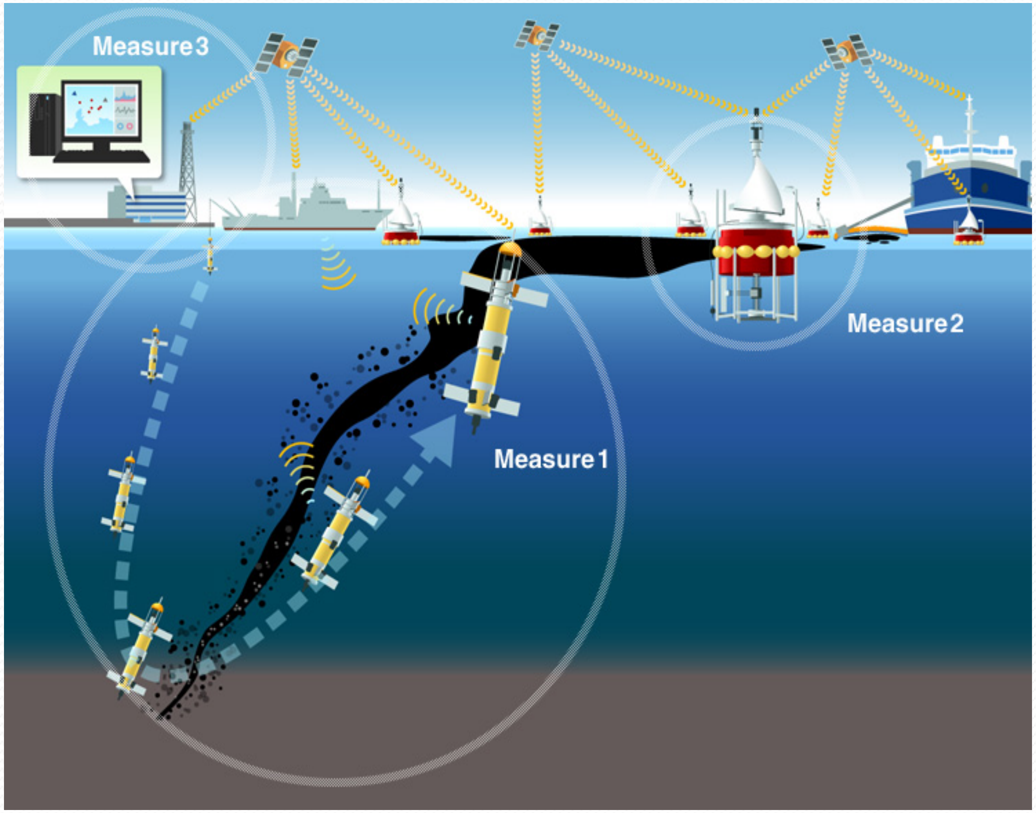
⇒ Highly accurate drifting simulation using real time data around spilled oil

Academic Challenges

- **Real time sensing of phenomena with Multi-scale (production and decomposition of gas hydrate) and Multi-Physics (thermal dynamics and hydrodynamics of production and decomposition of gas) in actual sea**
- **Highly accurate prediction of drifting oil and gas using real time data assimilation from robots**

Objectives

1. Autonomous tracking and monitoring of spilled plumes of oil and gas from subsea production facilities by an underwater buoy robot (Measure 1)



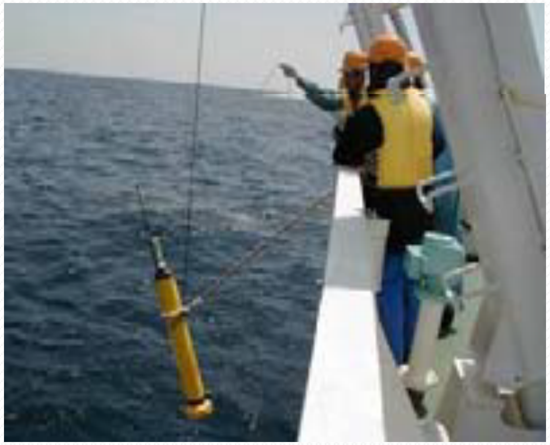
2. Autonomous tracking of spilled oil on the sea surface and transmission of useful data to a land station through satellites in real time by multiple floating buoy robots (Measure 2)

3. Improvement of the accuracy of simulations for predicting diffusion and drifting of spilled oil and gas by incorporating the real-time data from these robots(Measure

Underwater Robot for Autonomous Tracking and Monitoring of Spilled Plumes of Oil and Gas from Seabed (SOTAB-I)

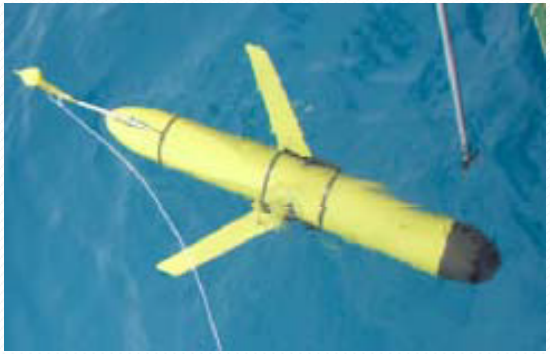
- Existing methods for marine environmental monitoring in 3-D space from sea surface to deep water over the long term

Argo Float



It floats vertically and repeats descending and ascending in the vertical direction. However, it does not have a function of active movement in the horizontal direction.

Underwater Glider



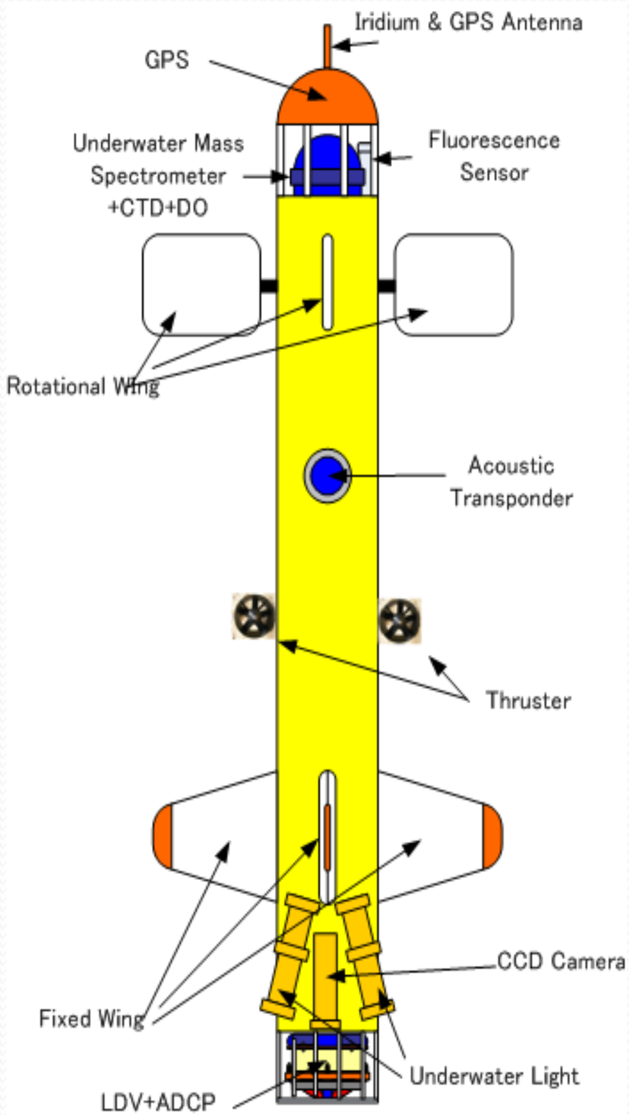
It has a streamlined body with fixed wings. It can descend and ascend by using a buoyancy control device, while it moves in the horizontal plane like a glider for long distance. However, the ratio of vertical movement distance to horizontal movement distance is small.

SOTAB-I

Prototype

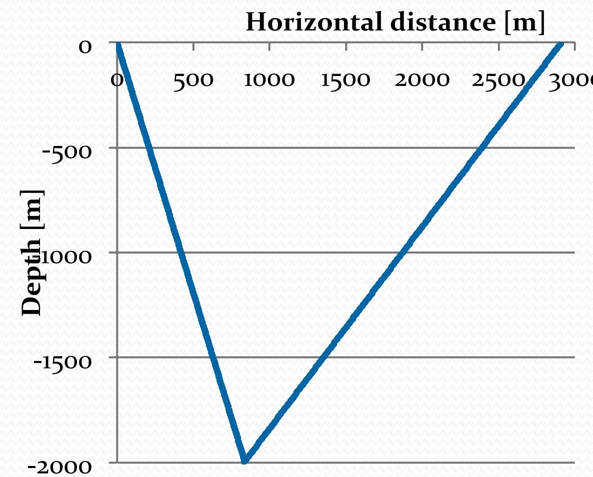
Length: 3.020 m
Diameter: 0.267 m
Mass:
116.0 kg

New type



Performance

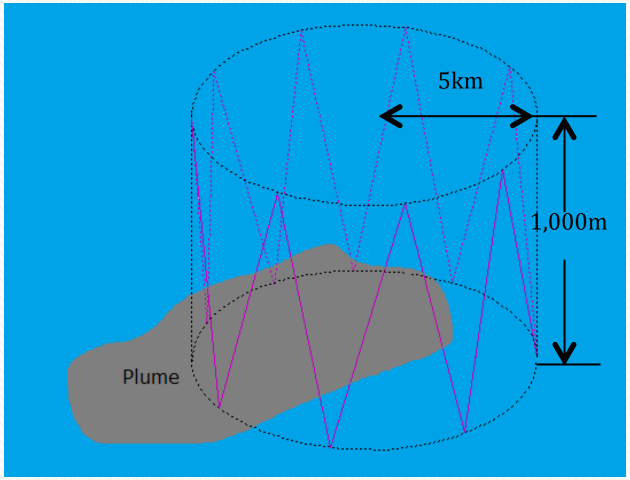
Descending and ascending
of 2,000 m water depth
with almost the same
horizontal movement as
in vertical movement



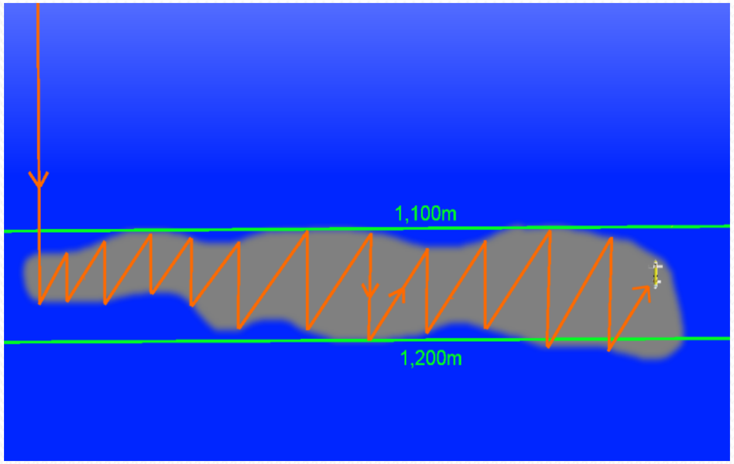
Actuators
Sensors
Communication
Localization

Guidance & Control of SOTAB-I

Rough Guidance for finding plumes of oil and gas (α mode)



Precise Guidance for measuring the structure of plumes of oil and gas (β mode)



It takes 33 hours for 11 times of descending and ascending along cylindrical surface with radius of 5 km and height of 1 ,000 m.

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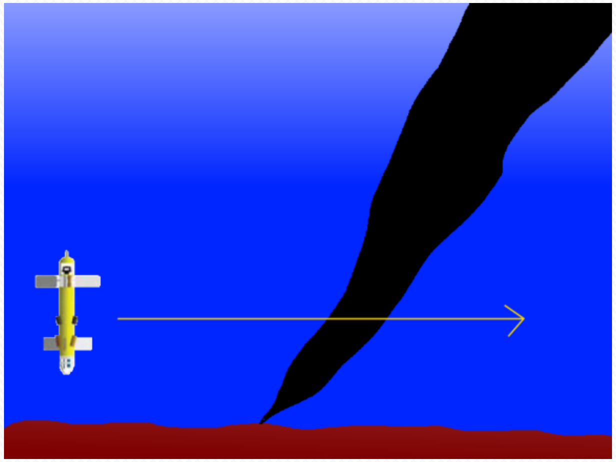
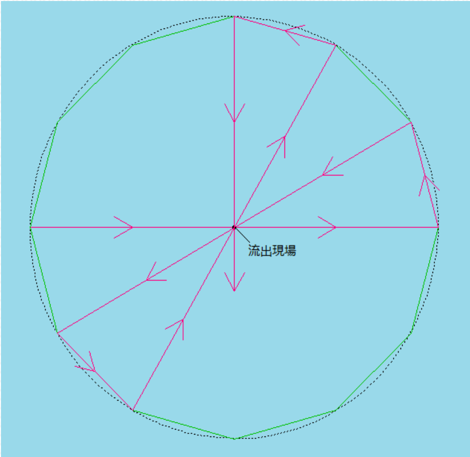
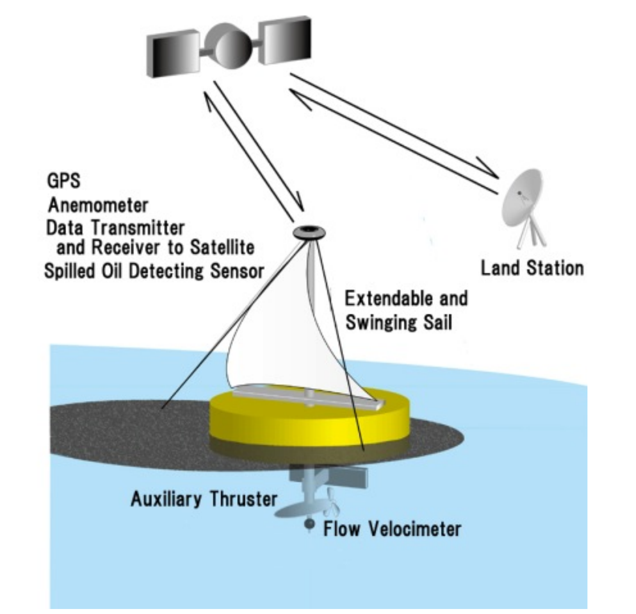
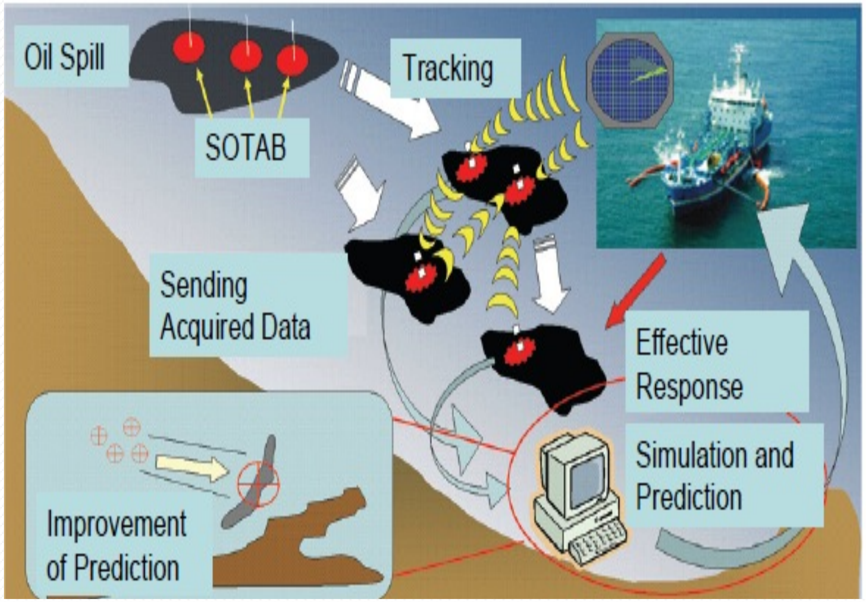
Precise Guidance for observation of blowout of plumes of oil and gas (γ mode)





Floating Buoy Robot Autonomously Tracking Spilled Oil Slick Drifting on Sea Surface(SOTAB-II)





Mission: **Multiple SOTAB-IIs follow the drifting oil slick automatically and send the positioning data and hydrographic phenomena at those positions to the operation base in real time.**

The buoy is equipped with a fluorescence sensor, GPS, an anemometer, an iridium satellite communication device on the top of the mast.

Existing methods

Existing methods for searching or tracking spilled oil

- **Fluorescence Lidar**

  Imaging system detecting excited fluorescence of substances using CCD camera

  This system mounted on a helicopter or a small airplane can provide the spreading image of spilled oil and classification of oils.

  Limited searching time

- **Observation Buoy:**

  Deployed on the sea and continuously detects the spilled oil.

  It cannot track the spilled oil, if the spilled oil drifts apart form buoy.

- **Remote Sensing**

  Sensors mounted on a space satellite can provide the spreading image of spilled oil and classification of oils.

  This system sends the data only several times in a day

- **X-band Radar**

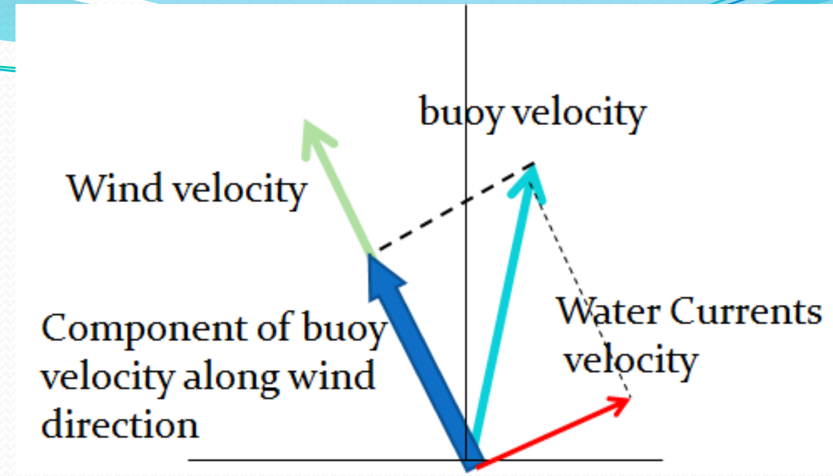
  Sensors mounted on a ship can provide the spreading image of the spilled oil.

  This system cannot be used for buoy.

Test Beds Studies

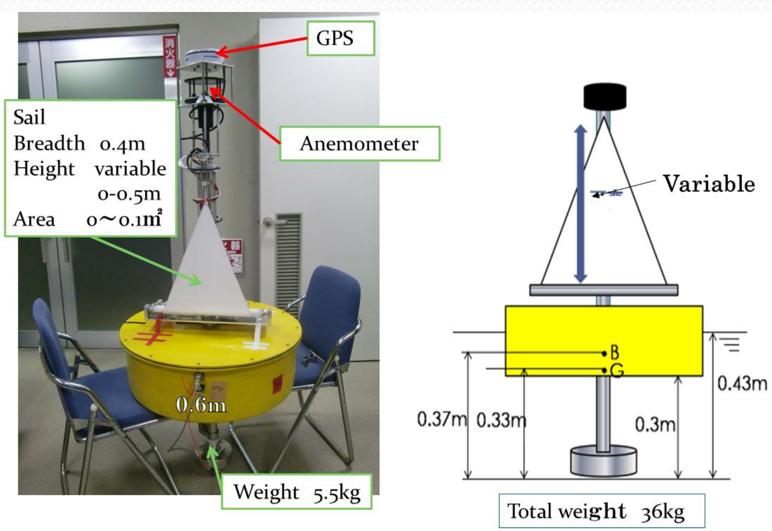
- **Buoy Velocity**

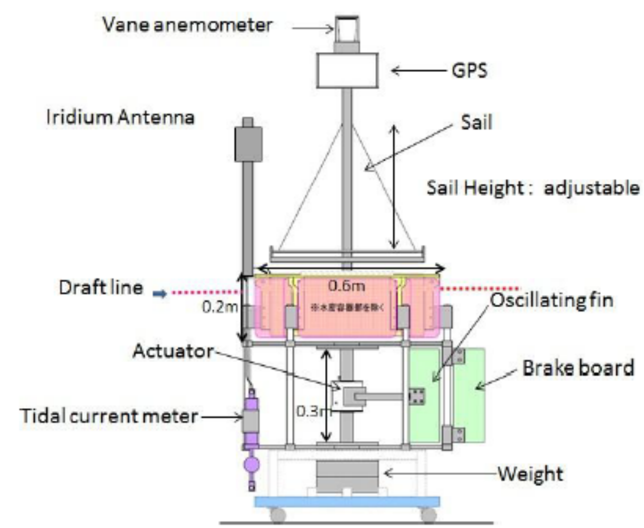
**Vector of velocity of buoy =
Vector of water currents +
Vector of 2-5 % of wind at
10 m above sea level**



SOTAB-II(ver.2)

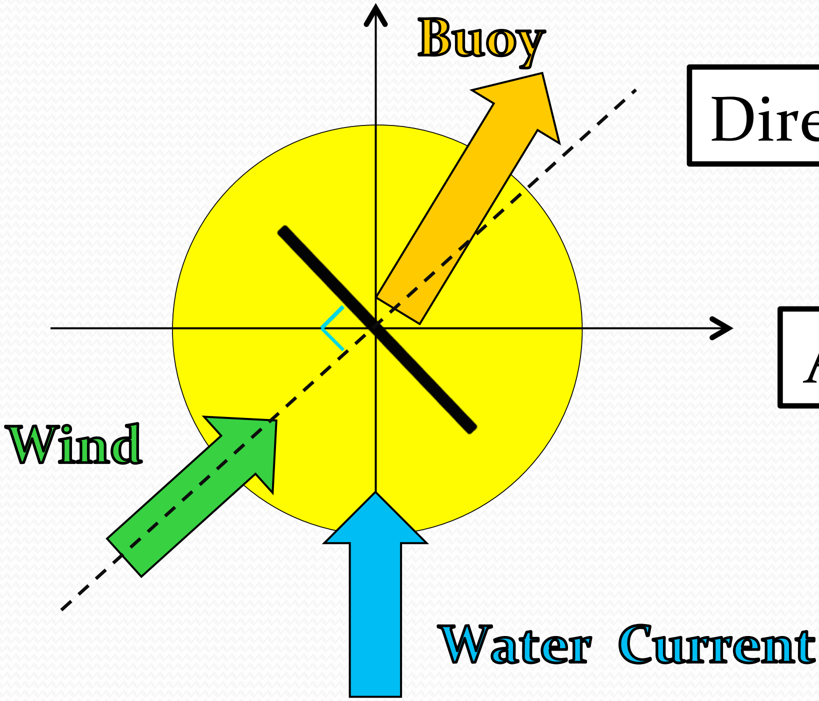
SOTAB-II(ver.1)





(height of 1.9 m, mass of 60.0 Kg)

Control Law



Direction of Sail: Perpendicular to wind direction

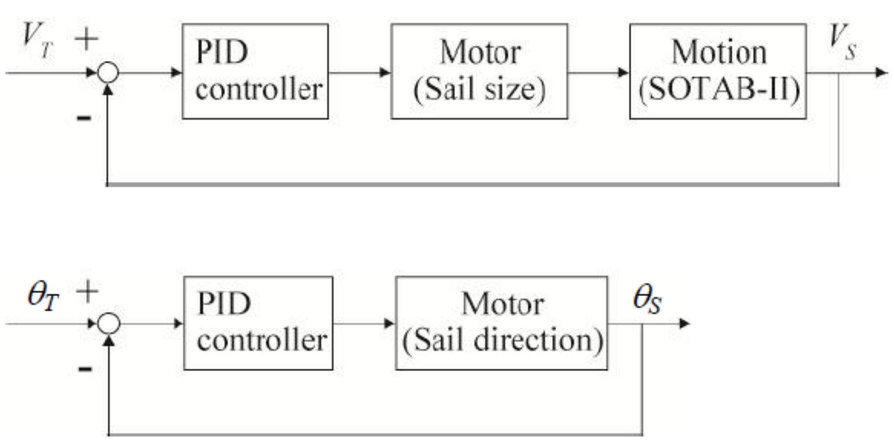
Area of Sail:

Speed of buoy > Speed of oil → Smaller area

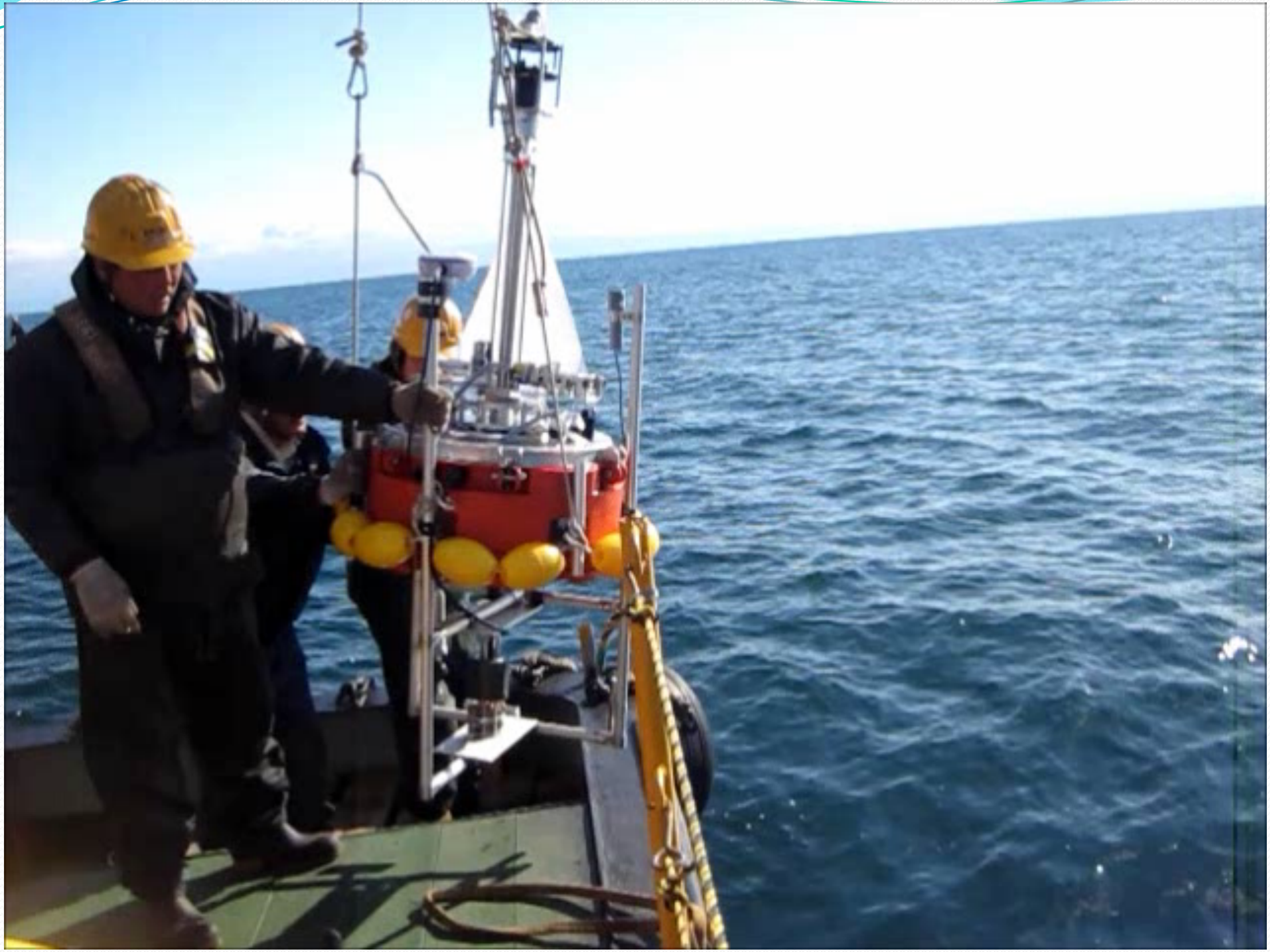
Speed of Buoy < Speed of oil → Larger area

GPS→Velocity vector of Buoy

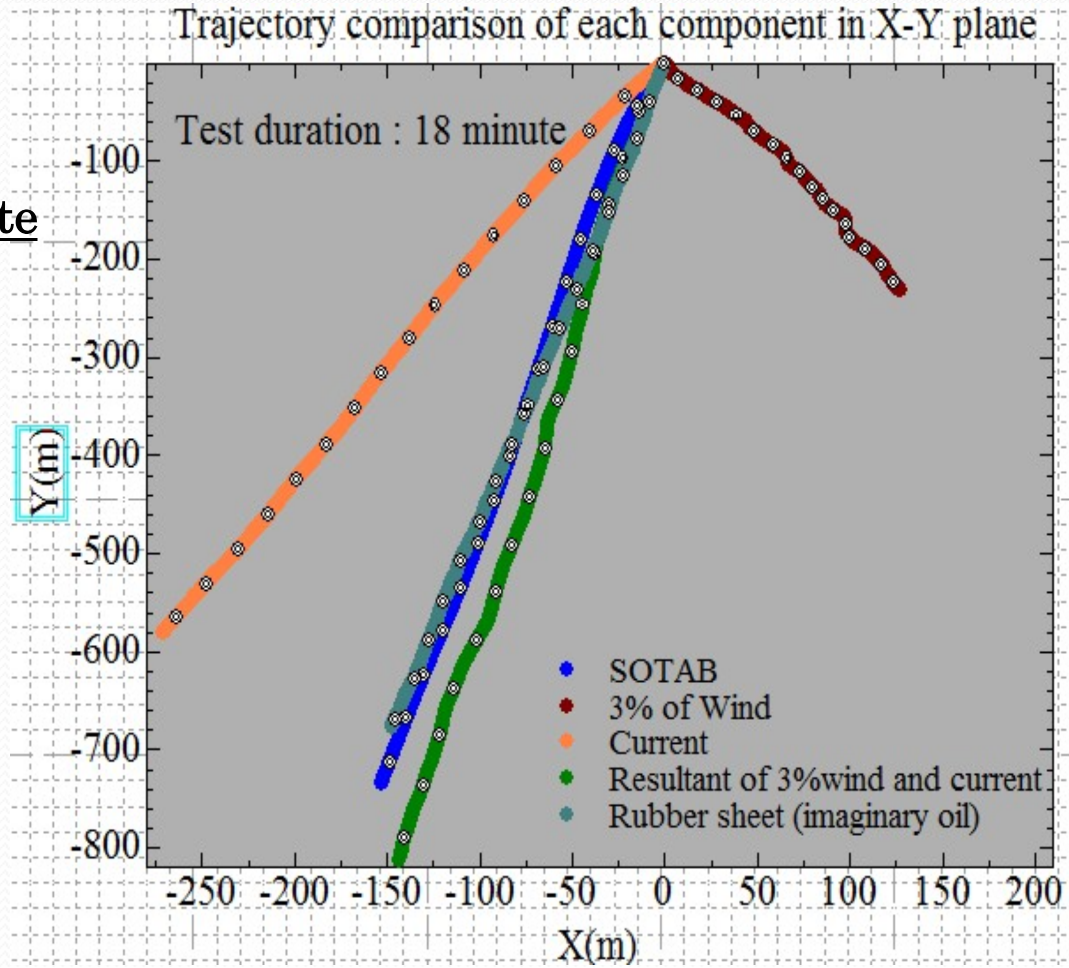
Anemometer
Compass
Velocimeter
→Estimated velocity vector of drifting oil



Sea trials off the coast of Awaji Island in Dec. ,2011



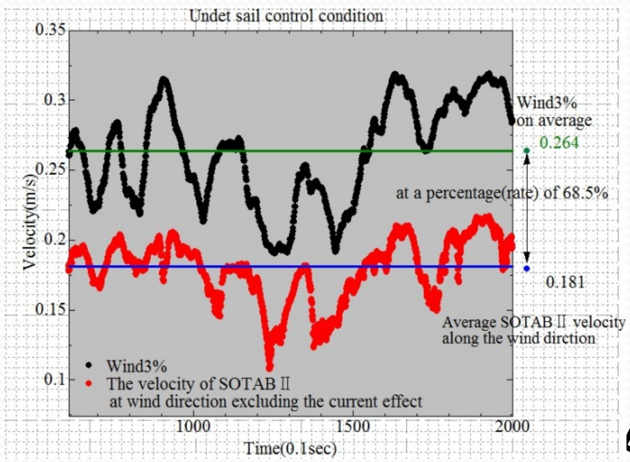
Sea Trials



Tidal current speed : 0.4-0.6 m/s
Wind speed : 8.0-10.0 m/s

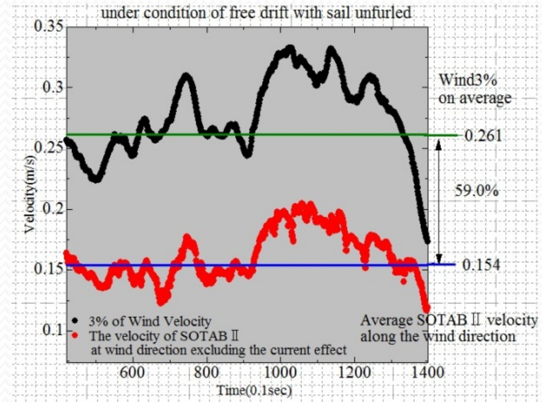
Effectiveness of sail control

Under control	Without control



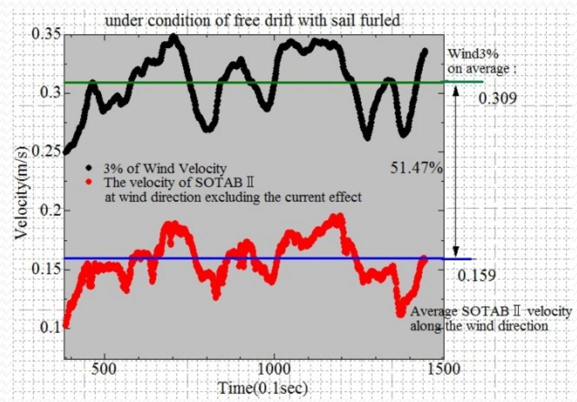
68.5% of 3% wind velocity

Expanded Sail



59.01% of 3% wind velocity

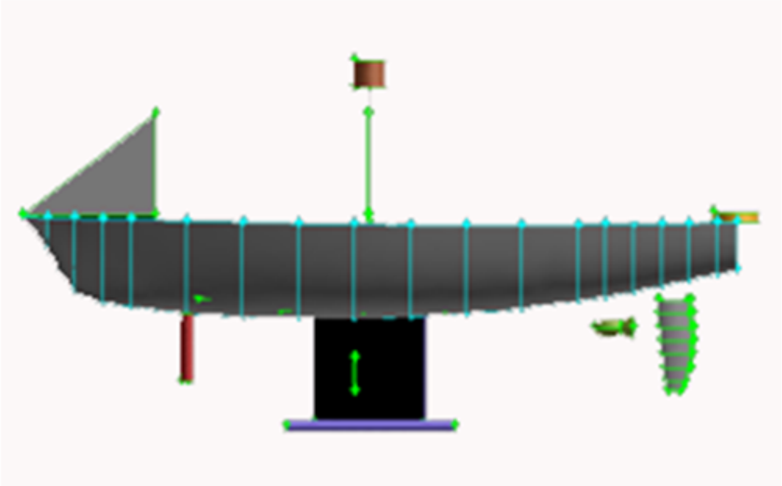
Furled Sail

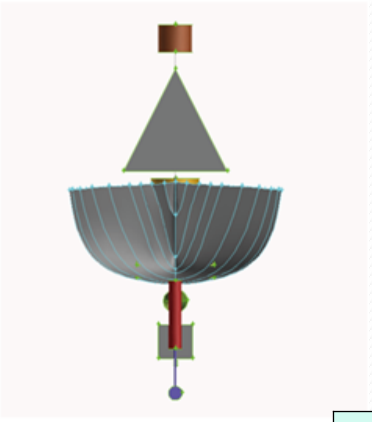


51.47% of 3% wind velocity

With control（68.5%） ＞ without control、Expanded sail （59%） ＞ without control、Furled sail （51%）

New design of SOTAB-II





- Decrease of Hydrodynamic Drag on body in water
- Installation of a fluorescence sensor mounted on the top of the mast for detection of spilled oil on sea surface, anemometer, velocimeter , GPS and Irijium
- Consideration of displacement for all instruments, performance of tracking spilled oil, dynamic stability and maneuverability

DIMENSIONS		
HULL		
LOA	[m]	2.136
LWL	[m]	1.71
BMAX	[m]	0.608
BWL	[m]	0.484
Displacement(DWL)	[kg]	27.68
Displacement(2WL)	[kg]	52.56
Deck Area	[m2]	0.89

Estimation of Number of Multiple SOTAB-IIs

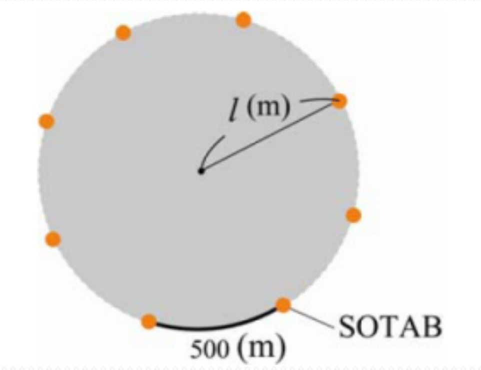
Assumptions

1. The amount of the oil (Vo) spills initially at the beginning of oil spill accident.

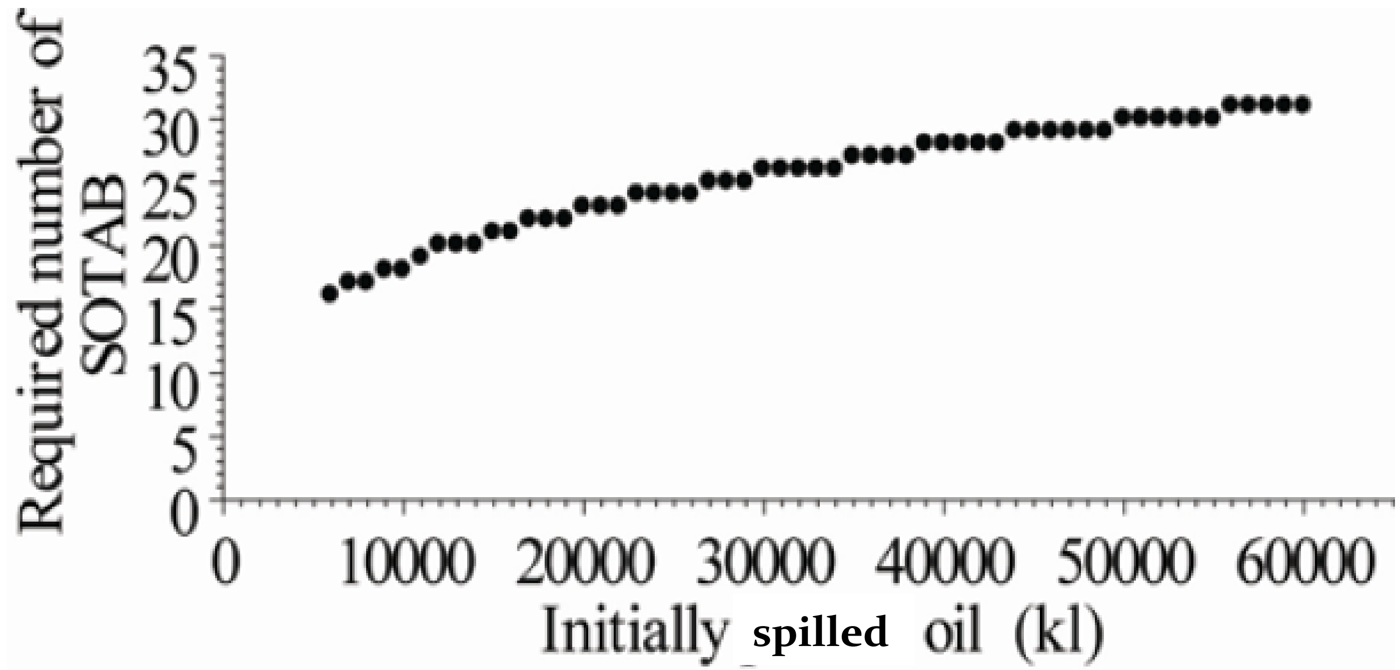
2. Such spilled oil spreads in a circle with radius of ℓ m in 24 hours. We arrange SOTAB-IIs around the edge of this circular spilled oil with the interval of 500 m, where the radius of diffusion is calculated as follows.

$$l_{1,t} = C_1\left(\Delta g V_E t^2\right)^{1/4} \qquad (0 \sim 1\,\text{hour})$$

$$l_{2,t} = C_2\left(\frac{\Delta g V_E^2 t^{3/2}}{\nu_E^{1/2}}\right)^{1/6} \qquad (1 \sim 24\,\text{hours})$$



The details should be referred in the text in the Proceedings.



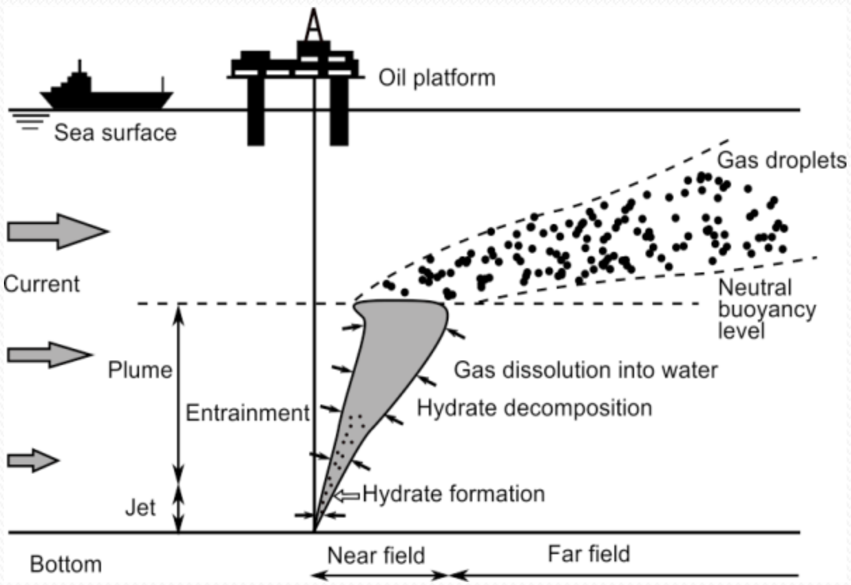
In the case of Nakhodka oil spill accident in 1997, the initially spilled oil was 6,700 kl, and 16 SOTAB-IIs will be required.
In the case of Exxon Valdez that spilled oil in 1989 at the amount of 42,000 kl, 28 SOTAB-IIs will be required.

Simulations for predicting diffusion and drifting of spilled oil and gas by incorporating the real-time data from SOTAB-I and SOTAB-IIs

- **Model Evaluation of Behavior of Oil and Gas from Deepwater Blowouts**

A model incorporating the phase changes of gas, associated changes in thermodynamics and its impact on the hydrodynamics of plume is evaluated taking hydrate formation, hydrate decomposition, gas dissolution, and non-ideal behavior of the gas into account.

1st stage: the behavior of gas plume is initially dominated by its dynamics

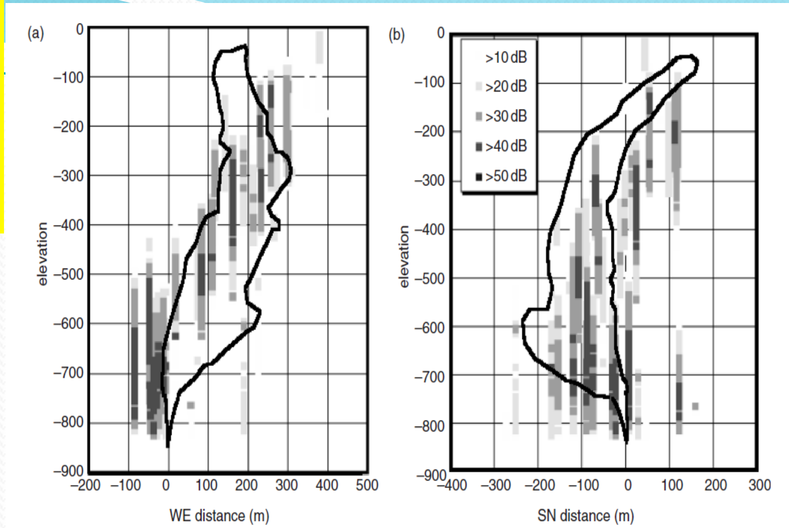


2nd stage: A jet/plume may reach a neutrally buoyant level, and the plume behavior is more governed by the advection and diffusion.

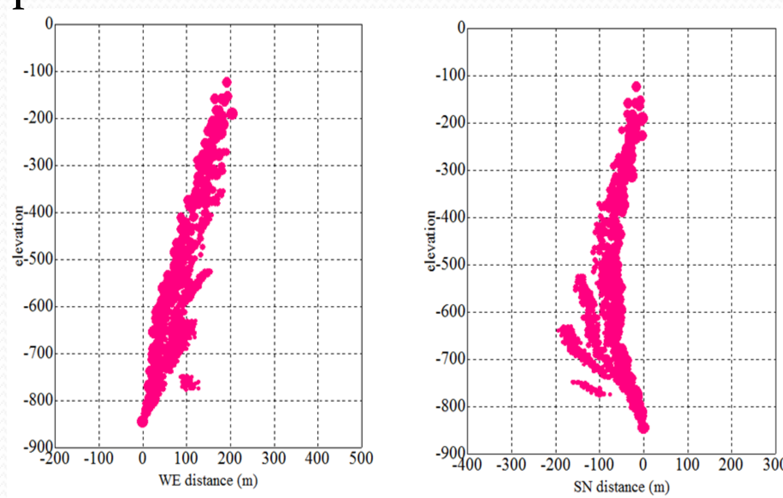
Model of Blowout of Oil Droplets

Blowout of oil droplets is modeled to compare the DeepSpill experiment conducted in the Norwegian Sea at the Helland Hansen site in 844 m of water roughly 125 km off the coast of central Norway.

In the simulation, water temperature, salinity and ambient current velocity are imposed at each sea level. The distribution of oil droplet size is also given. The model represents the behavior of oil droplets using unsteady motion of oil droplets in the vertical direction and diffusion of oil droplets in horizontal plane.



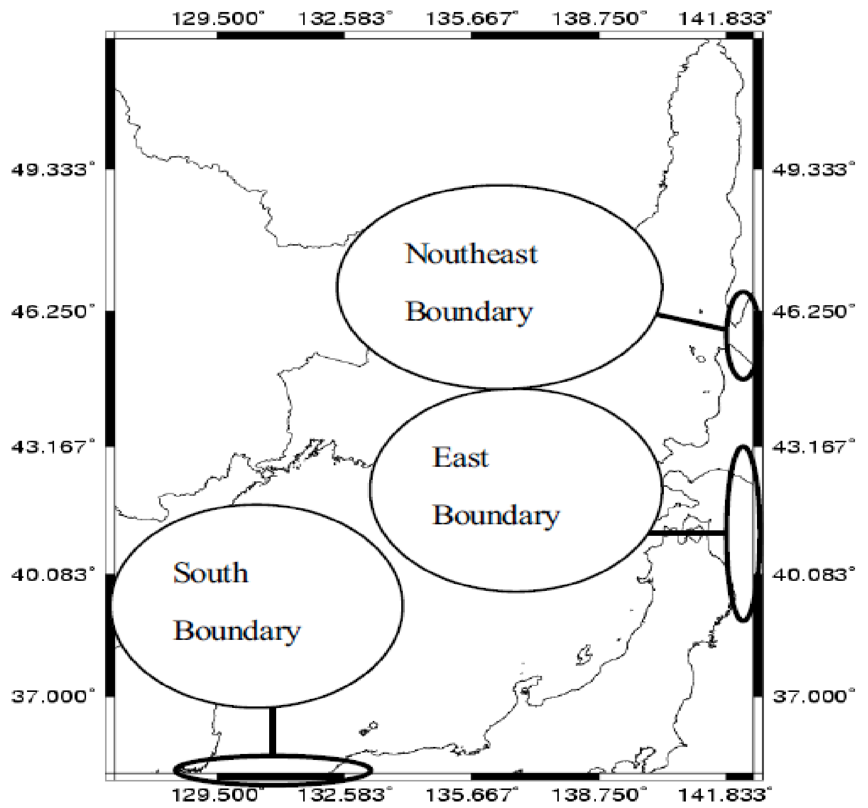
Side views of Echo Sounder data and CDOG simulated profile(thick line) at the DeepSpill experiment



Side views of the simulated profile of behavior of oil droplets using the proposed model

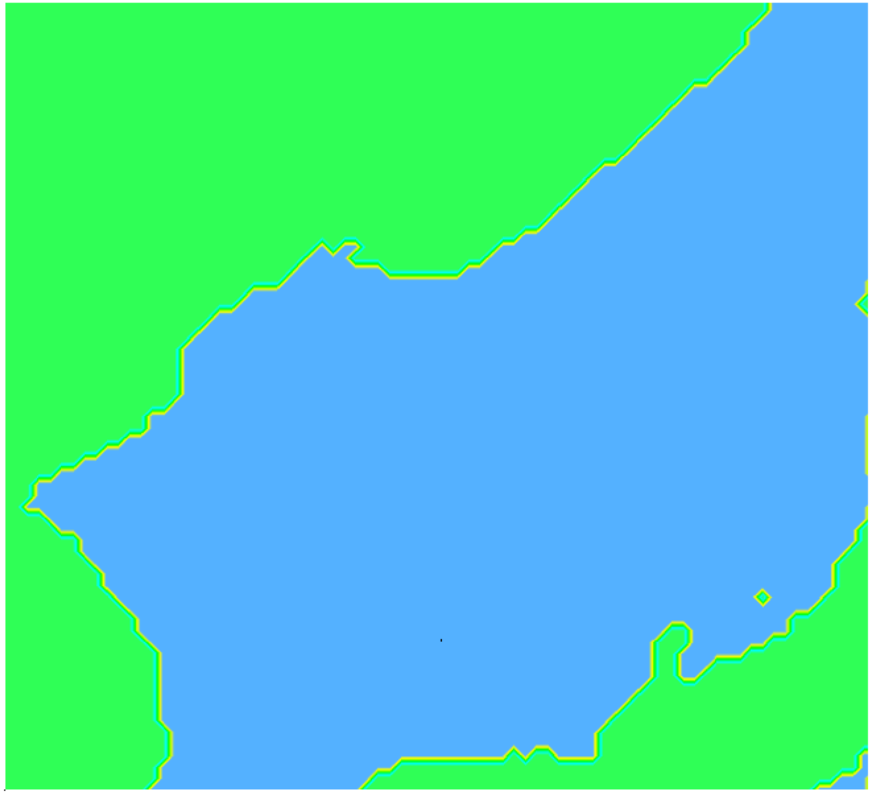
Assimilation of Weather Research and Forecasting(WRF) in the Model of Drifting of Spilled Oil on Sea Surface

- A combination of Princeton Ocean Model(POM) for ocean modeling and WRF Model is used for the prediction of drifting of spilled oil on sea surface in this study.
- To raise the accuracy of prediction of drifting of spilled oil on sea surface, this study adopts variational data assimilation method for WRF Model and POM using data from SOTAB-II and others.
- Simulation of the drifting of spilled oil after the incident of the Russian tanker Nakhodka in the Sea of Japan in January 1997 is performed to evaluate the effectiveness of data assimilation method.

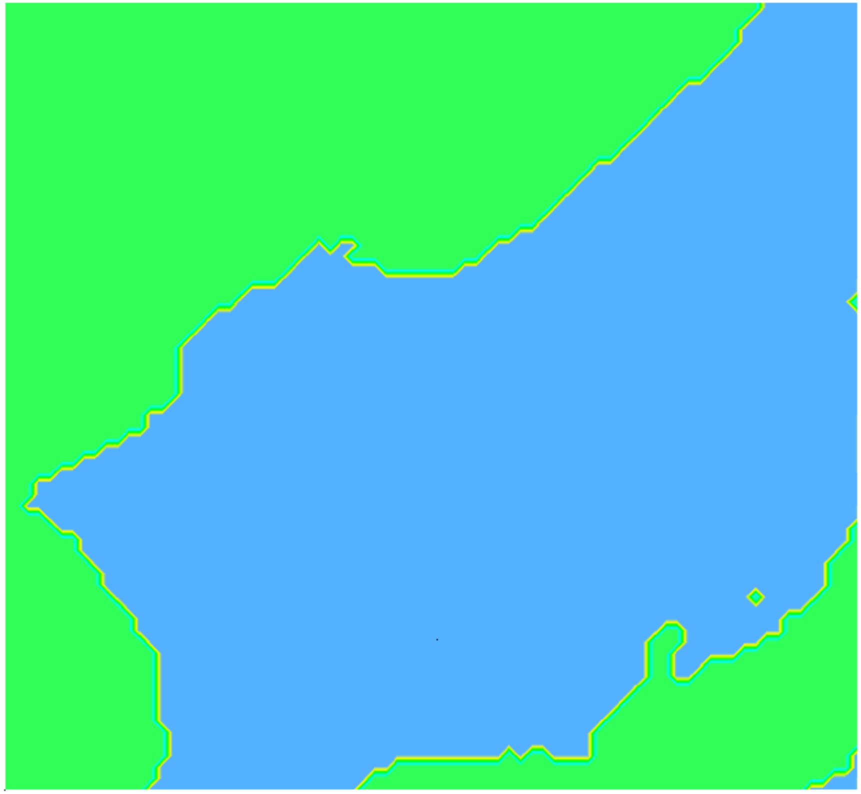


Model		WRF	WRFDA	POM
Calculation domain	North latitude	34°～53°	34°～53°	34°～53°
	East longitudinal	127°～142.5°	127°～142.5°	127°～142.5°
Grid size		18km×18km	18km×18km	18km×18km
Time step		Δt＝60(sec)	Δt＝120(sec) (4DVAR)	Δt＝12(sec)
Assimilation time window			±1 hour (3DVAR)	
			+6 hours (4DVAR)	
Calculation period		1/1 ,1997~ 1/31,1997	1/1 ,1997~ 1/31,1997	1/1 ,1997~ 1/31,1997
Initial value and Boundary value		NCEP Reanalysis: 2.5 degree resolution, every 6 hours		Tide level Water temperature Salinity Forced flow
Observed value		･NCEP ADP Operational Global Surface Observations ･NCEP ADP Operational Global Upper Air Observations		

SYNOP and SOUND data are given to WRFDA as the observed data.



Without Data Assimilation



With 3-D Var. Data Assimilation

Table Comparison of ratio of collected spilled oil at prefectures in Japan after Nakhodka oil spill accident

Name of Prefecture	Measured(%)	Without Data Assimilation(%)	3-D Variational Data Assimilation (%)
Shimane Tottori	0.60	9.19	4.98
Hyogo	2.90	2.16	1.37
Kyoto	7.30	9.26	5.11
Fukui	37.30	54.50	47.28
Ishikawa	44.30	21.08	30.60
Niigata	7.60	4.24	10.26
Others		1.12	1.94
	RMS Error(%)	12.41	7.31

Concluding Remarks

- Sea experiments will be carried out using SOTAB-I in the areas of Gulf of Mexico and off Niigata where methane gas is spilled, and using SOTAB-IIs in the area of Norway where actual oil is dispersed.

Acknowledgements

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Thank you for your kind attention !